The hole through Torghatten mountain: nature's own artwork and an object of risk evaluation

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Torghatten is a 258 m high mountain located on the coast of Northern Norway, close to the town Brønnøysund. The mountain is famous for the big hole, an approximately 160 m long, 35 m high and 15-20 m wide natural tunnel, crossing the mountain, see Fig. 1.

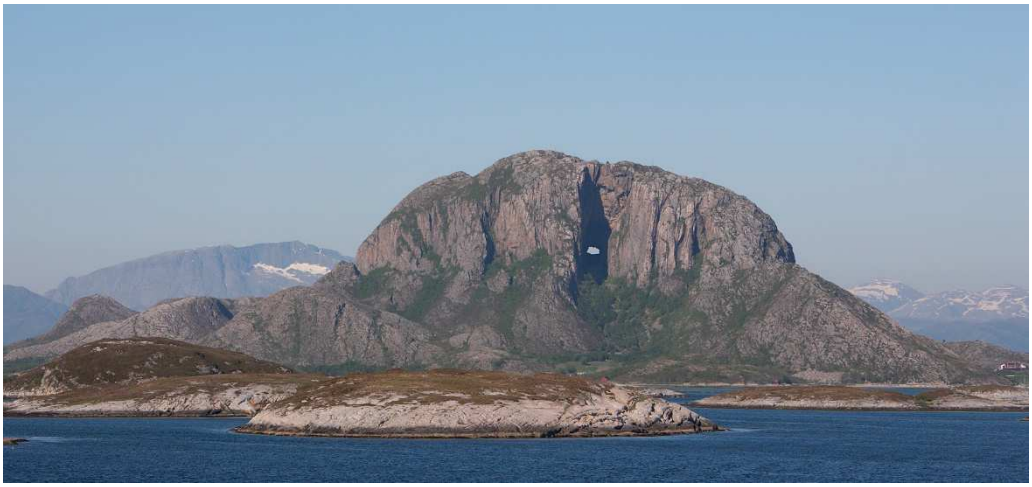

Fig. 1. The hole through Torghatten mountain as seen from the Southern side.

The hole is oriented NE-SW, which coincides with the strike of the foliation and distinct discontinuities in the area. Several of these can be observed in the roof of the cavern, and the two most prominent of the distinct discontinuities form the walls of the hole, see Figs. 2-4. The bedrock in the area consists of Paleozoic granitic gneiss of mainly good quality, but along the hole the rock mass is weaker and more fractured.

The hole is located at a level of approximately 130 meters above present sea level, and is believed to have been formed by glacial erosion and wave erosion through thousands of years, when the sea level was higher than today.

The hole through the Torghatten mountain is a major tourist attraction, with about 42,000 visitors every year (according to statistics published by local newspaper in 2014). The great majority of tourist visits are during the summer season (May-August). The access to the

hole and the trail through it have been prepared to some extent by the local authorities, but visit to this location is on own risk. Some few incidents of rock fall have been experienced during the last decades. These have occurred mainly during autumn, winter and spring (October-March), particularly as result of frost wedging and heavy rainfall.

Fig. 2. The entrance to the hole from North. Note persons standing at the entrance to the lower left.

The safety for tourists visiting this attraction has been a main concern. Regular inspections for evaluating stability and evaluations of potential measures for reducing risk therefore have been carried out at regular intervals, in most cases by the author as scientific advisor for SINTEF. Most importantly based on these inspections, the trail leading to the hole and through it has been relocated to "safe location" so that the risk of being hit by rock fall has been minimized, and unstable blocks above the entrance to the hole (to the upper right in Fig. 2) have been scaled down.

Any comprehensive rock support such as rock bolting and sprayed concrete are unrealistic for aesthetic reasons. Stability evaluation based on discontinuity mapping has shown that large scale instability is highly unlikely due to the fact that the main structures cause a wedging of the rock mass between, as shown in Figs. 2-3, in such a way that release of large

volumes is not kinematicly possible. However, rock fall of smaller volumes is still a risk, particularly during periods of heavy rainfall and frost wedging.

Fig. 3 The northern and central parts of the hole.

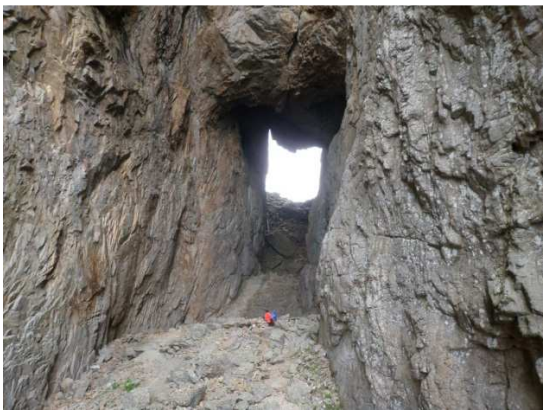

Fig. 4. The southern and central parts of the hole.

The risk of rock fall therefore is still an important issue, and discussions on what risk level should be regarded acceptable has therefore come up. This is a type of discussion which is often relevant also for other underground objects of public interest, such as karstic caves and visitor mines.

Based on event-tree type of analysis and probabilistic approach, and taking into account that the great majority of tourist visits are during May-August, i.e. the period with no frost wedging and lowest precipitation, the annual risk of person being hit by rock fall has been estimated to less than 10^{-4}, which is well below the general acceptance level (DSB, 2011).

References:

DSB (2011): *Guidelines for technical regulations according to the planning and construction law - Chapter 7: safety requirements regarding nature disasters* (in Norwegian). Directorate for Public Protection (DSB), Oslo.